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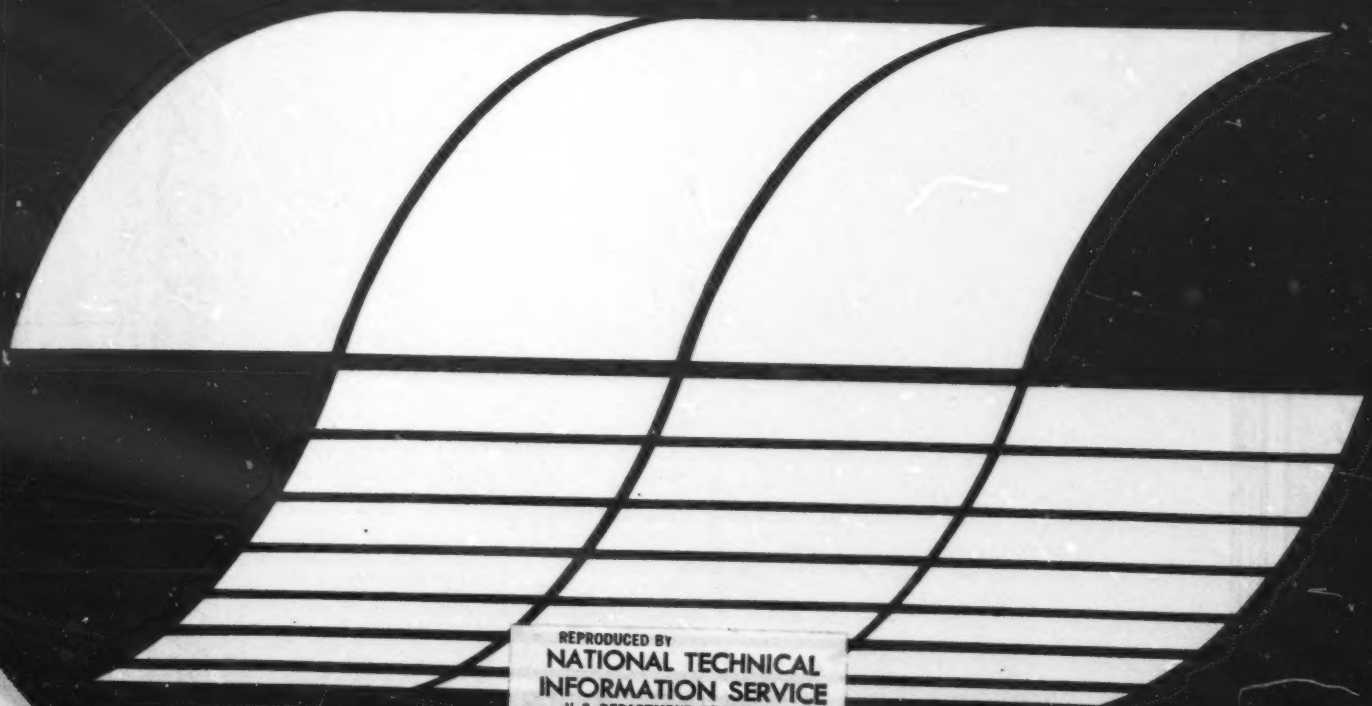

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Airborne measurements of aerosols and polluted gases in urban and power plant plumes were conducted during the summer of 1975, February 1976, and February 1977 in the vicinity of St. Louis, Missouri; Moss Landing, California; and Clearwater, Florida, respectively. The principal objective was to characterize the physical and chemical behavior of these plumes under a variety of meteorological conditions, with emphasis on sulfur transport and transformation. Results illustrate the regional nature of air pollution. The transport of well-defined urban plumes over 150 km downwind of a city was documented during day and night conditions. Power plant plumes were sampled over 100 km downwind of the source at night and during the day over the ocean; strong dilution mechanisms limited the sampling of power plant plumes to 40 km during the day over land. Measurements indicated that, when the plume was not well mixed to the ground, the mass flux of sulfur in the plume did not change with distance. In urban plumes, a significant reduction in sulfur was found; only about one-third of the emissions were transported beyond 100 km downwind of the city.

New techniques used in this study included an airborne impactors system for aerosol collection and atmospheric electrical measurements for plume tracting.

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ABSTRACT

Airborne measurements of aerosols and pollutant gases in urban and power plant plumes were conducted during the summer of 1975, February 1976, and February 1977, in the vicinity of St. Louis, Missouri; Moss Landing, California; and Clearwater, Florida, respectively. The principal objective was to characterize the physical and chemical behavior of these plumes under a variety of meteorological conditions, with emphasis on sulfur transport and transformation. Results illustrate the regional nature of air pollution. The transport of well-defined urban plumes over 150 km downwind of a city was documented during day and night conditions. Power plant plumes were sampled over 100 km downwind of the source at night and during the day over the ocean; strong dilution mechanisms limited the sampling of power plant plumes to 40 km during the day over land. Measurements indicated that, when the plume was not well mixed to the ground, the mass flux of sulfur in the plume did not change with distance. In urban plumes, a significant reduction in sulfur was found; only about one-third of the emissions were transported beyond 100 km downwind of the city.

A new airborne impactor system was tested during the program. Sample substrates were optimized for microscopy, but elemental composition of the samples was also determined using ion-excited X-ray emission techniques. A preponderance of sulfur was found in all types of samples (regional, urban plume, power plant plumes). The dominance of sulfur in regional samples obtained in a large scale hazy air mass is indicative of the role played by sulfur in visibility reduction.

Atmospheric electrical measurements were made to test their effectiveness in plume tracking. Power plant plumes were detected up to 90 km from the source using conductivity and potential gradient sensors.

This report was submitted in fulfillment of Contract 68-02-2245 by Meteorology Research, Inc. under the sponsorship of the U. S. Environmental Protection Agency. This report covers a period from June 18, 1975 to October 18, 1977, and work was completed October 18, 1977.

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SECTION 1

INTRODUCTION

The fate of sulfur compounds emitted into the atmosphere from urban areas and industrial processes has become an issue of great importance in the formulation of air pollution control strategies. As part of the EPA-sponsored Project MISTT (Midwest Interstate Sulfur Transformation and Transport), airborne sampling was conducted by Meteorology Research, Inc. (MRI) in the plumes from oil-fired power plants in California and Florida, from coal-fired plants in the vicinity of St. Louis, and from the St. Louis urban/industrial area. Preliminary measurements were made during the summer of 1973, followed by large-scale field programs in 1974, 1975, 1976, and 1977. These aircraft-based measurements were designed to provide data useful in answering many unresolved questions about the transport, transformation, and removal processes affecting atmospheric sulfur.

The principal objective of the MRI sampling programs was to characterize the physical and chemical behavior of plumes (both urban and power plant) under a variety of meteorological conditions. Particular areas of interest were to:

1. Measure primary and secondary pollutant mass fluxes in the plume at a number of distances downwind of the source;

2. Characterize plume behavior during daytime (well-mixed) and nighttime (stable) regimes;

3. Determine the composition of aerosols in the plume and in background air;

4. Document the transport, accumulation, and transformation of pollutants in synoptic-scale air masses.

Analyses of the aircraft data were directed towards gaining a better understanding of the factors affecting the transport, transformation, and removal of primary and secondary pollutants, particularly those containing sulfur. Among these factors were temperature, solar radiation, humidity, vertical mixing, wind velocity, background pollutant concentrations, and trace element (catalyst) concentrations.

During the sampling performed under this contract, two new aerosol sampling techniques were tried. An airborne impactor system capable of collecting aerosol samples for microscopic and elemental analyses was developed and used to collect samples during the summer 1975 and February 1977 field programs. A description of the system and analysis of the data from the summer 1975 program are presented in Section 5. During the February 1977 field program, atmospheric electrical measurements (conductivity and potential gradient) were made in conjunction with other aerosol measurements to determine their usefulness as in-situ and/or remote aerosol indicators (10).

The primary sampling platform for the work performed under this contract was an instrumented Cessna 206, operated by MRI. Measurements obtained by the Cessna 206 included SO_2, NO, NO_y, O_3, light-scattering coefficient (b_{SCAT}), condensation nuclei, aerosol charge acceptance, aerosol size distributions, temperature, dewpoint, ultraviolet radiation, pressure, and position. The aircraft was equipped to collect aerosol samples for chemical and microscopic analyses using cascade impactors and a size-segregating sequential filter sampler. Data from the instruments, as well as several status indicators, were recorded on magnetic tape cartridges approximately once per second. During most sampling missions, the Cessna 206 was supported by a scout aircraft. The scout was used to locate the plume, to aid in determining the sampling path for the primary aircraft, and to make limited measurements at far downwind distances. During the Summer 1975 field program the scout aircraft was a Cessna 182 operated by Washington University. During the February 1977 program, a Bellanca Viking, operated by Airborne Research Associates, was used both as a scout and as the sampling platform for the atmospheric electrical measurements.

Project MISTT was a multi-year effort involving a team of several research groups. Organizations that participated in Project MISTT are listed in Table 1, along with a brief description of their responsibilities. Overall program direction was provided by the Environmental Sciences Research Laboratory of the U. S. Environmental Protection Agency at Research Triangle Park, North Carolina. The field programs in the St. Louis area were coordinated by Washington University.

This report describes the field programs conducted during July/August 1975, February 1976, and February 1977. The emphasis is to describe the MRI sampling programs and experimental methods, and to summarize the results and conclusions of analyses of the MRI aircraft data. An analysis of the elemental composition of aerosol samples collected during the summer of 1975 program is also presented in this report. The previous field programs and analyses of the earlier data are reported in the final report for the 1974 program (1). Where appropriate, significant differences between the 1974 program and later work are pointed out in this report.

TABLE 1. PROJECT MISTT PARTICIPANTS

Airborne Research Associates:	Electric Field Measurements, Scout Aircraft.
Argonne National Laboratory:	Boundary Layer Structure and Dynamics, Dry Deposition Rates. (ANL work was co-sponsored by ERDA.)
Battelle Columbus Laboratories:	Outdoor Smog Chamber Measurements of Sulfate Formation Rates in St. Louis, Gas Chromatographic--Mass Spectrometric Measurements of Organic Vapors.
California Institute of Technology:	Development of a Supersensitive Sulfate Measurement Technique, Sulfate Measurements--1974.
Crocker Nuclear Laboratory (University of California, Davis):	Aerosol Sample Analysis using IEXE techniques.
Environmental Measurements, Inc.:	COSPEC Measurements.
Environmental Quality Research:	Forecasting and other Meteorological Support, Dry Deposition Studies.
EPA-Las Vegas:	Helicopter Measurements, Winter 1976, Aircraft Lidar Observations, Summer 1976.
EPA-Research Triangle Park:	Program Management, Instrument Calibration, Data Transfer, Measurements in EPA Mobile Lab.
Florida State University:	Aerosol Measurements Using the FSU "Streaker" Sampler with PIXE Analysis.
IIT Research Institute:	Optical and Electron Microscopy.
Meteorology Research, Inc.:	Aircraft Measurements, Data Analysis, Meteorological Interpretation.
University of Minnesota:	Aerosol Size Distribution Measurements, Aerosol Dynamics, Ground Measurements, Data Analysis, and Interpretation.
Northrop Services, Inc.:	Instrument Calibration, Program Coordination--1977.
Rockwell International Science Center:	Pilot Balloon Operations.
Stanford Research Institute:	Ground-Mobile Lidar Operations.
University of Texas:	Effects of Charge on Aerosol Deposition, Reactive Plume Models.
Washington State University:	Detailed Hydrocarbon Analysis, Interpretation of Ozone and Hydrocarbon Data.
Washington University:	Field Program Direction, Scout Aircraft Operations, Data Analysis and Interpretation, Data Management and Model Development, Sulfate Determinations.
University of Washington:	Ground-Based Measurements and Data Interpretation, Sulfate Species Measurement, Air Mass Trajectories.

SECTION 2

SUMMARY OF RESULTS, CONCLUSIONS, RECOMMENDATIONS

RESULTS

A total of thirty-one sampling missions were conducted during the summer 1975 (St. Louis, Missouri), February 1976 (Moss Landing, California), and February 1977 (Clearwater, Florida) field programs. Of these, nine were devoted to urban/industrial plumes, six to coal-fired power plant plumes, fifteen to oil-fired power plant plumes, and one to a study of synoptic-scale hazy air masses. Urban and power plant plume studies were conducted both day and night, and in some cases sampling continued into the following day. Much of the oil-fired power plant plume sampling was performed over the ocean.

Analyses of the data base resulting from these thirty-one sampling missions have yielded significant gains in understanding the physical and chemical factors affecting the transport and transformation of primary and secondary pollutants. The major contributions of MRI to the airborne sampling programs were to collect the aircraft data, analyze the meteorological facors affecting plume behavior and analyze the urban plume data. Other investigators studied the physical and chemical properties of plume aerosols, the fate of sulfur in the plume, the properties of synoptic-scale polluted air masses, and other related aspects of pollutant behavior. Both the results of MRI analyses and of analyses performed by other researchers using data collected by MRI during the summer 1975, February 1976, and February 1977 field programs are summarized in this chapter.

Urban Plumes

A large portion of the data from the summer 1975 field program was related to urban plumes. MRI analyses of the urban plume data are reported in References 2-6. The results of these analyses were summarized by by Wilson (7):

1. The urban plume of St. Louis significantly degraded the air quality of communities as far as 150 km from the city on a number of occasions. An example of such an occasion is depicted in Figure 1.

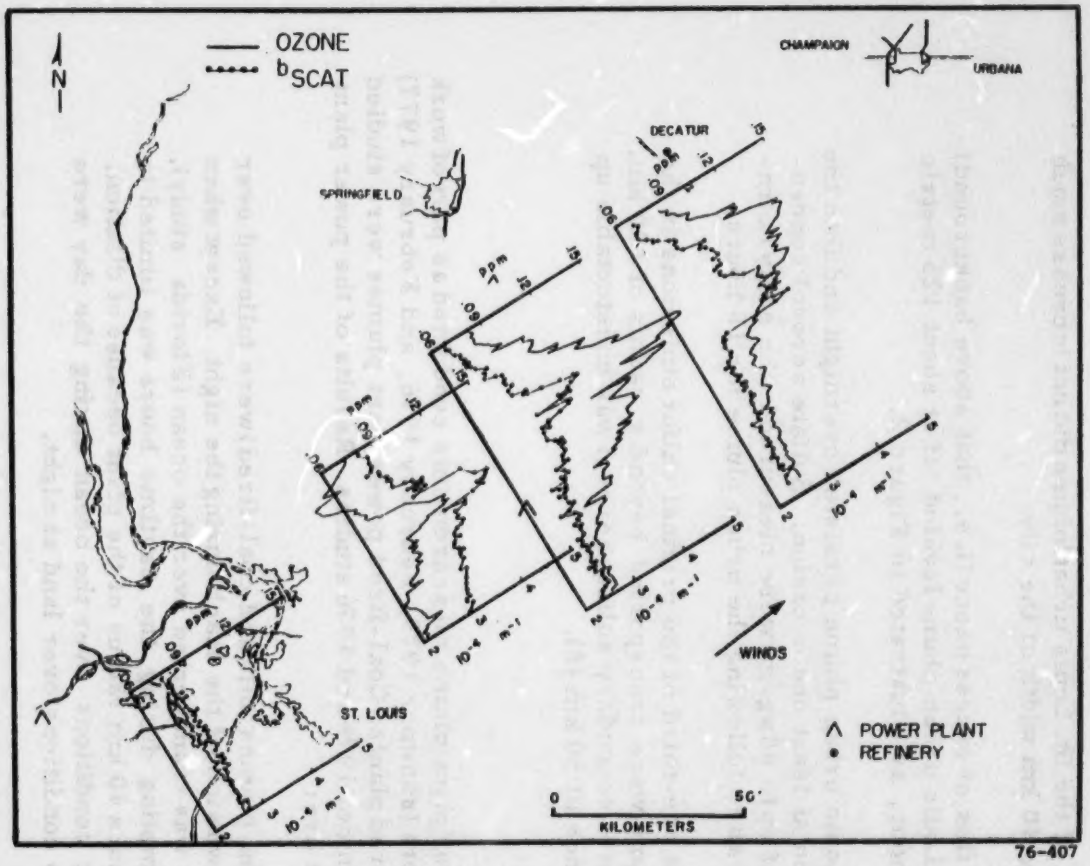

Figure 1. Selected horizontal profiles of ozone concentration and b_{SCAT} downwind of St. Louis on 11 August 1975. Profiles were recorded during traverses of profile baselines at the following altitudes and times: (starting upwind of city) 455 m msl, 0744-0758 CDT: 425 m msl, 1019-1036 CDT; 610 m msl, 1245-1310 CDT; 760 m msl, 1442-1058 CDT. Note that baseline concentrations are non-zero.

2. The most conspicuous components of the St. Louis plume 50 km or more downwind of the city were the reaction products formed along the way, particularly ozone and light scattering aerosols (b_{SCAT}).

3. Most of the aerosol responsible for the high b_{SCAT} and resulting decrease in visibility within the St. Louis urban plume was formed after 1-2 hours reaction time in the atmosphere.

4. The width of the St. Louis urban plume did not increase much beyond the 40 km width of the city.

5. The mass flux of excess ozone (i.e., that above background) in the St. Louis urban plume leveled off at about 125 metric tons per hour, as illustrated in Figure 2.

6. The St. Louis urban plume persisted overnight and into the next day on at least one occasion. Sulfate aerosol concentrations of up to 60 $\mu g/m^3$ were measured in the early morning hours after following the urban plume for 18 hours.

7. Only about one-third of the original sulfur emissions in the urban plume were transported beyond a radius of 100 km. Formation of secondary sulfate aerosol was undetectable up to a distance of 50 km (8).

Power Plant Plumes

Most of the power plant plume measurements conducted as part of work described in this report (summer 1975, February 1976, and February 1977) were related to oil-fired plants. Coal-fired power plant plumes were studied extensively in the summer 1974 and 1976 studies. Results of the power plant plume measurements are:

1. Power plant plumes (oil- and coal-fired) were followed over 100 km downwind of the stack during the night. Except when the plume was transported over the ocean (Florida study), plume sampling during the daytime hours was limited to within about a 40 km radius of the plant because of dilution. Transport conditions over the ocean during the day were similar to conditions over land at night.

2. Within the limits of experimental uncertainty, when the plume was not well mixed to the ground, the mass flux of of sulfur in the plume did not change with distance (8).

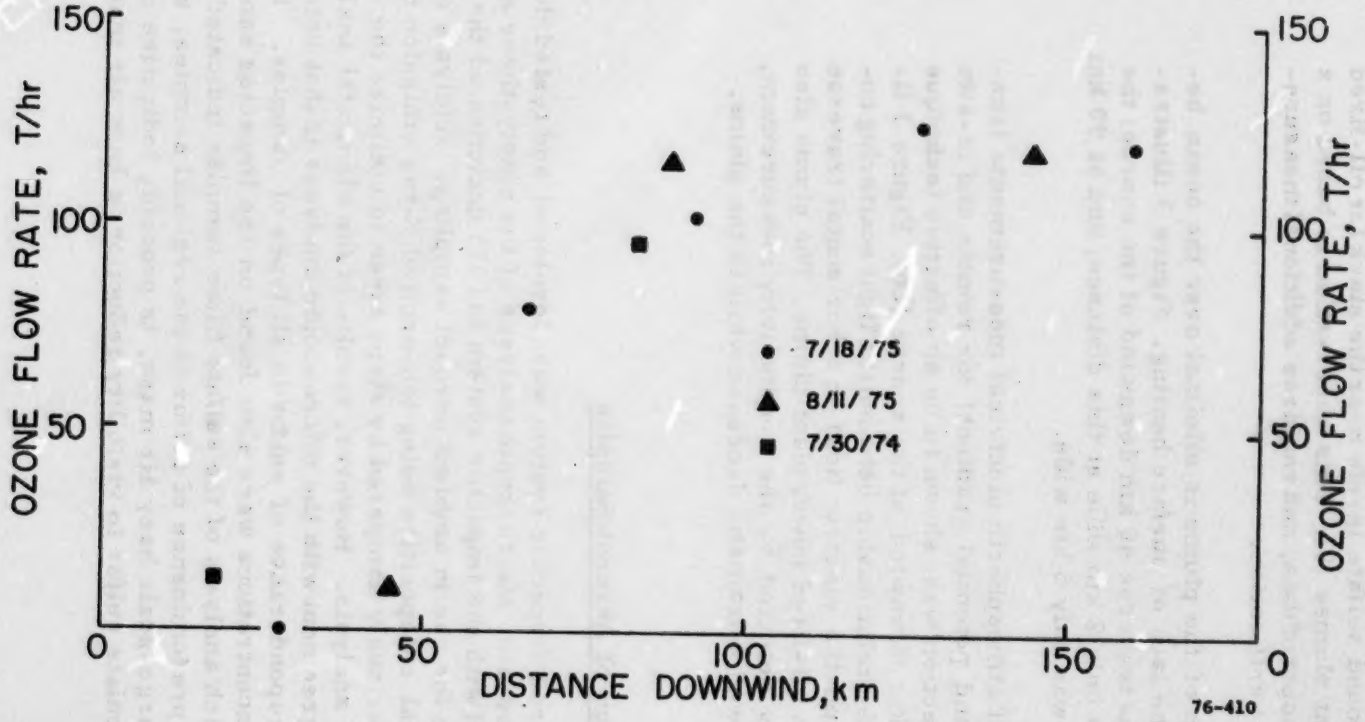

Figure 2. Ozone flow rates (in excess of background) in St. Louis urban plume on three different days. Values are calculated from winds within the plume and the difference between ozone concentrations inside and outside the plume. Downwind distances are measured from St. Louis Gateway Arch.

3. The sulfate formation rate in the oil-fired power plant plumes studied appeared to be considerably lower at night than during the day (9).

4. Fallout of sulfate particles may be a significant contributor to ground sulfate levels near the stack for oil-fired power plant plumes (9). This observation is based on a limited amount of data, and requires additional measurements for verification.

5. Dispersion of the plume is minimal over the ocean because of the lack of surface heating. Figure 3 illustrates a plume traverse 40 km downwind of the source; the plume was only 2 km wide at this distance, and at 90 km downwind was only 5 km wide.

6. The use of atmospheric electrical measurements (conductivity and potential gradient) for remote and in-situ plume detection was shown to be an effective technique out to 90 km downwind of the source (10). Figure 3 illustrates the relationship between the light scattering coefficient and the electric field on a horizontal traverse through an oil-fired power plant plume. The plume also was easily detected by the conductivity measurement, which showed a dramatic decrease while in the plume.

Elemental Composition of Aerosol Samples

The MRI airborne impactor system was developed and tested during the 1975 sampling program. Microscopic analyses of the ninety-three aerosol samples collected with the impactor system in 1975 documented the feasibility of the system for use in ambient aerosol sampling. Analysis of the samples for elemental composition using ion-excited X-ray emission techniques (IEXE) was seriously hampered by steps taken to optimize the samples for microscopic analysis. However, results of the elemental analyses were in qualitative agreement with the microscopic analyses in that both analyses indicated a preponderance of sulfur in all types of samples. Likewise, high sulfur concentrations were also found on the impactor samples on those days for which analysis of the sulfate filter samples indicated high sulfate levels. The predominance of sulfur in the regional samples, which were collected in a large-scale hazy air mass, is probably indicative of the contribution of particulate sulfur to visibility reduction in hazy air masses.

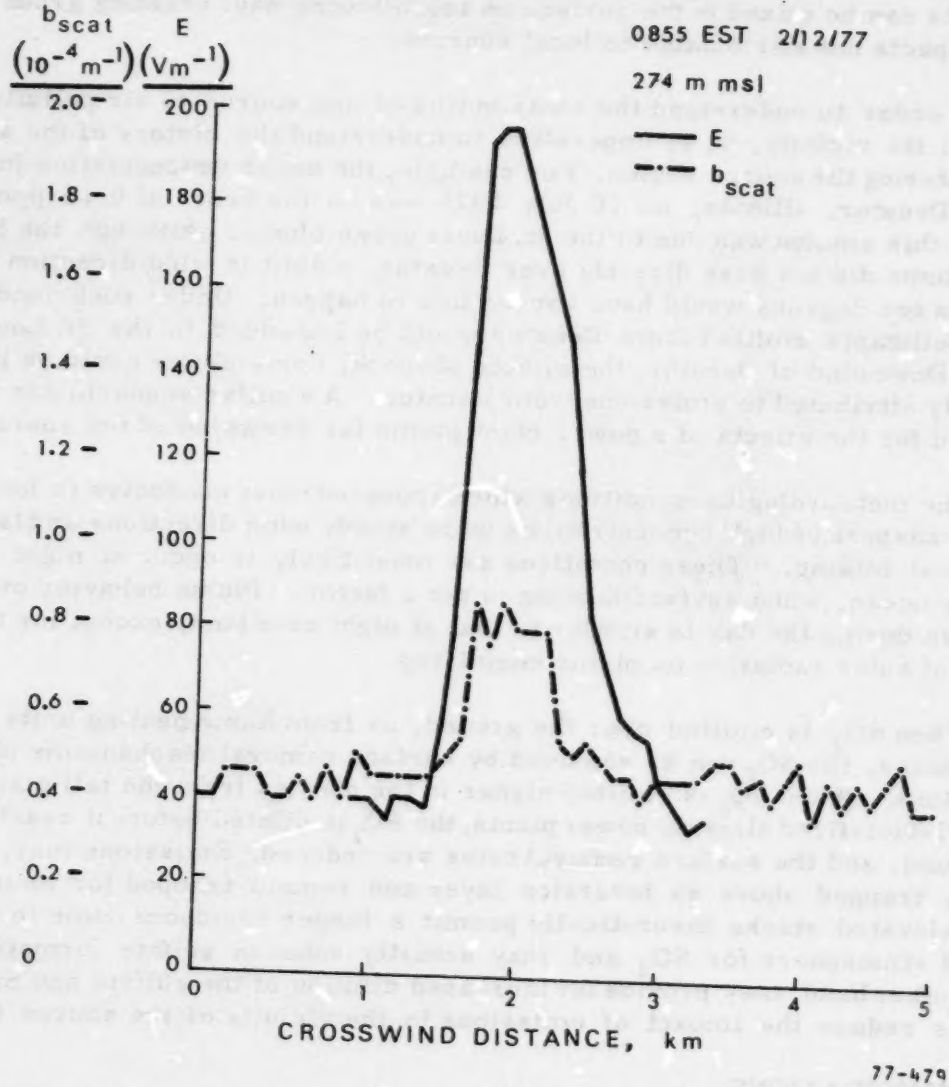

Figure 3. Comparison of light scattering coefficient (b_{SCAT}) and vertical electric field (E). Data recorded from two aircraft flying in formation through an oil-fired power plant plume 40 km downwind of the source.

CONCLUSIONS

Air pollution in the midwest United States must be considered as a regional problem in the formulation of air pollution control strategies. Both urban and power plant plumes can be transported long distances. At night, elevated plumes are isolated from the surface and can travel at least 100 km downwind of the source in the absence of strong removal processes. These pollutants can be mixed to the surface on the following day, creating ground-level impacts not attributable to local sources.

In order to understand the contribution of any source to air pollution levels in its vicinity, it is imperative to understand the history of the air mass entering the source region. For example, the ozone concentration just east of Decatur, Illinois, on 18 July 1975 was on the order of 0.15 ppm. Much of this amount was due to the St. Louis urban plume. Although the St. Louis plume did not pass directly over Decatur, a shift in wind direction of less than ten degrees would have caused this to happen. Under such conditions, pollutants emitted from Decatur would be imbedded in the St. Louis plume. Downwind of Decatur, the effects of the St. Louis plume could be incorrectly attributed to emissions from Decatur. A similar scenario can be imagined for the effects of a power plant plume far downwind of the source.

The meteorological conditions which appeared most conducive to long-range transport of high concentrations were steady wind directions and lack of vertical mixing. These conditions are most likely to occur at night or over the ocean, when surface heating is not a factor. Plume behavior over the ocean during the day is similar to that at night over land, except for the effects of solar radiation on plume chemistry.

When SO_2 is emitted near the ground, as from home heating units or short stacks, the SO_2 can be removed by surface removal mechanisms (dry deposition). When SO_2 is emitted higher in the air, as from the tall stacks of fossil-fuel-fired electric power plants, the SO_2 is diluted before it reaches the ground, and the surface removal rates are reduced. Emissions may, in fact, be trapped above an inversion layer and remain trapped for hours. Thus, elevated stacks theoretically permit a longer residence time in the ambient atmosphere for SO_2 and may actually enhance sulfate formation. On the other hand, they provide for increased dilution of the sulfate and SO_2 and thus reduce the impact of emissions in the vicinity of the source (7).

RECOMMENDATIONS

The field measurements described in this report documented the existence of long-range pollutant transport, however they did not define the geographical extent of long-range transport nor the frequency of occurrence.

These two subject areas need to be better understood in order to define the impact of the long-range transport of pollutants. We recommend further analysis of the aircraft and supporting meteorological data to better determine the meteorological conditions leading to the development of long-range transport situations. This may allow the results of Project MISTT to be extended to other regions.

Further work is desirable in both analysis of existing data and collection of additional data. A wealth of plume chemistry data was collected during Project MISTT, and only a small fraction has been analyzed in detail. Analysis of these data should yield considerable insight into the chemical transformation processes occurring in both urban and power plant plumes and the meteorological factors affecting these processes.

Research areas where additional measurements are recommended are the three-dimensional distribution of pollutants on a regional (synoptic) scale, the behavior of plumes over the ocean, and the importance of particulate fallout as a sulfur removal mechanism from plumes. Measurements performed over the ocean are an approximation of smog chamber experiments in the free atmosphere, because of the virtual absence of surface sources and removal mechanisms. Preliminary measurements of the three-dimensional distribution of pollutants on a regional scale were performed on 10 August 1975, however much more work is needed to understand the factors affecting the transport, transformation, and removal of regional-scale polluted air masses. Finally, measurements made in February 1977 indicated that particulate fallout might result in significant surface sulfate concentrations near the stack, but much more work is needed to document the importance of this effect.

SECTION 3

PROGRAM DESCRIPTION

The overall program can be divided into four separate types of sampling missions: urban, coal-fired power plant, oil-fired power plant, and regional. Sampling was performed during July/August 1975, February 1976, and February 1977, at several locations across the United States (Figure 4). Summaries of all sampling missions are presented in this chapter. Detailed sampling maps, flight outlines, weather summaries, and data plots can be found in the data volumes for this project (11, 12).

URBAN PLUME

Emissions from the St. Louis urban/industrial area were sampled during July and August 1975. Other participants in urban plume sampling missions were Washington University (program coordination, scout aircraft operation, field data processing), University of Minnesota (aerosol size distribution measurements), Environmental Measurements, Inc. (ground-based correlation spectrometer SO_2 measurements), IIT Research Institute (microscopic analysis of aerosol samples), Northrop Services, Inc. (calibration of gas analyzers), and Rockwell International (winds aloft measurements).

A summary of the nine urban plume sampling missions is presented in Table 2.

COAL-FIRED POWER PLANT PLUME

Airborne sampling was conducted in the plume of the coal-fired Labadie power plant during July and August 1975. The Labadie plant (2250 megawatts) is located about 55 km west of the St. Louis Gateway Arch. This sampling was performed as part of the summer 1975 St. Louis program, and the other participants were the same as for the urban plume sampling missions.

A summary of the six coal-fired power plant plume sampling missions is presented in Table 3.

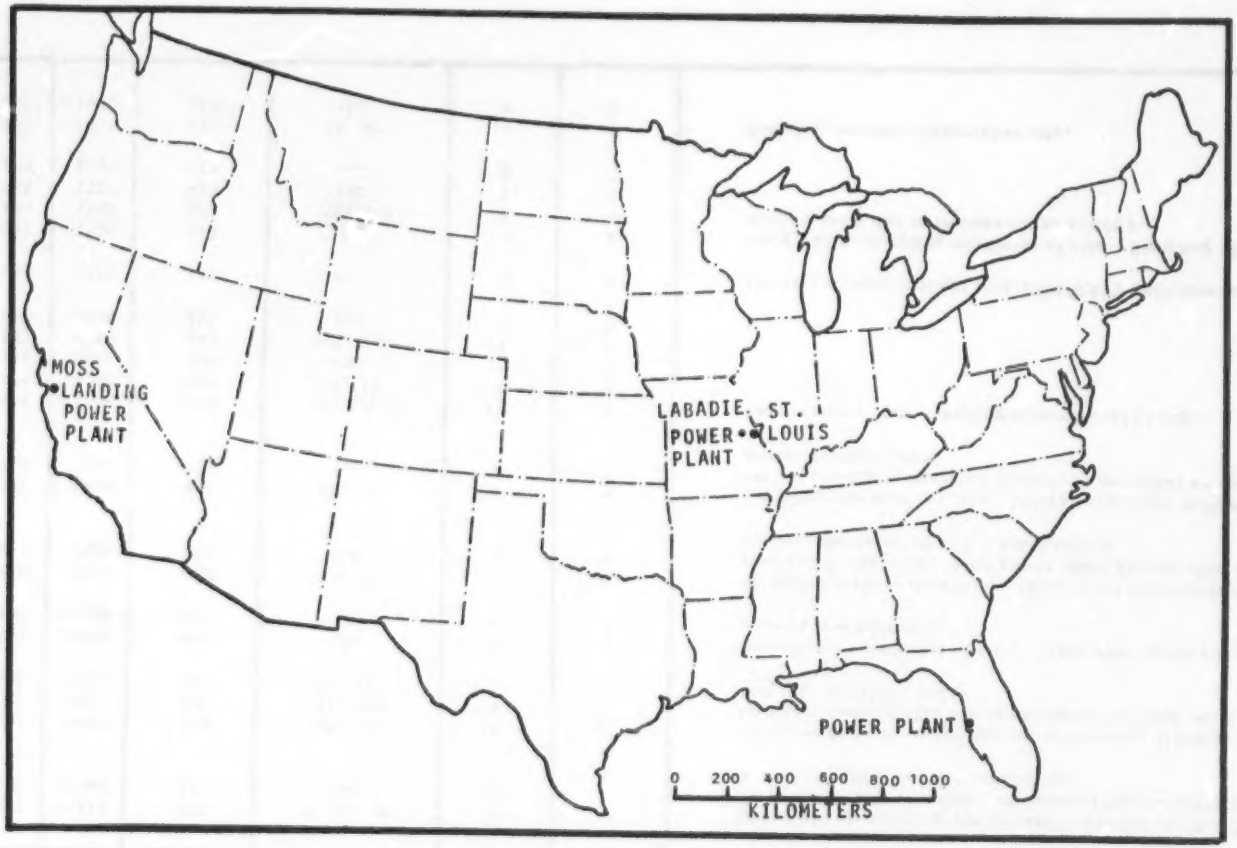

Figure 4. Location of sampling programs.

TABLE 2. SAMPLING SUMMARY--URBAN PLUME (ST. LOUIS, MISSOURI)

Date (1975)	Flight Times (CDT) Start	Stop	Tape Cartridge Number	Approx. Plume Sampling Dist. (km)	No. of Sulfate Samples	No. of Impactor Samples	Comments
7/17	0657	~1115	120	8, 30, 50	0	4	Urban plume sampling upwind and downwind of Alton/Wood River industrial complex. Afternoon flight terminated due to deteriorating weather conditions.
	~1215	~1340	127	50	0	0	
7/18	0641	0958	134	25, 32	10	2	Long-range plume sampling out to Decatur, Illinois. A detailed analysis of this day is presented in White et. al., Science, 194, pp. 187-189, 1976.
	1051	1451	135	75, 100	8	2	
	1545	1900	406	135, 175	8	0	
7/21	0638	~1000	415	~15	9	0	Sampling to southwest of city. Light wind speed conditions, poor plume definition.
	~1115	~1300	416	50	4	0	
7/22	0726	1126	408	15, 50	14	0	Sampling northwest of city. Alton/Wood River industrial complex and Portage des Sioux power plant plumes also sampled. Plumes not detected at 105 km distance.
	1237	1444	409	105	4	0	
7/28	1311	1640	452	10, 35	0	4	Sampling due south of city. Urban plume well defined at 35 km. Sampling terminated because of marginal weather conditions farther south.
	1724	1823	453	---	0	0	
7/29	1322	~1730	454	30, 50, 87	12	3	Long-range plume sampling to northwest of city.
&	1854	~2250	455	87, 120	8	1	
7/30	2350	0405	456	150	10	2	
	0505	0913	457	190, 250	12	2	
	1026	1246	458	250	3	0	
8/7	0803	0929	459	---	4	0	Cross-calibration flight with EPA/RAPS helicopters.
8/11	0737	1106	418	55	9	2	Long-range sampling northeast of city. Sampling at 240 km unsuccessful due to thunderstorm activity.
	1139	1532	422	90, 150	9	2	
	1608	1723	423	240	3	0	
	2007	2136	423	---	2	2	
8/12	0739	~1120	426	32, 80	4	2	Sampling to east-northeast of city.
	1236	~1600	427	160	3	2	

TABLE 3. SAMPLING SUMMARY--COAL-FIRED POWER PLANT PLUME (LABADIE POWER PLANT)

Date (1975)	Flight Times (CDT) Start	Stop	Tape Cartridge Number	Approx. Plume Sampling Dist. (km)	No. of Sulfate Samples	No. of Impactor Samples	Comments
7/19	0733	~0950	407	10, 22	0	0	Plume characterization to northeast of plant. Wind direction variable in afternoon.
	~1310	~1415	407	35	0	0	
7/24 & 7/25	2100	~0030	417	15, 25, 50	20	4	Nighttime sampling southwest of plant. Good plume definition at 88 km.
	0138	~0440	450	88, 145	12	1	
8/6	1641	~1950	460	10, 44	0	3	Plume not detected at 44 km distance.
8/7 & 8/8	1732	2106	461	2, 18, 39	9	4	Strong vertical dilution of plume at 2 km distance. Only traces of plume found on second flight.
	2227	~0150	462	58, 80	9	3	
8/8 & 8/9	2208	0145	420	16, 37, 93	8	4	Plume located at 93 km distance northwest of plant; however, pronounced wind shift prevented further sampling.
8/13	0643	0954	429	8, 21	21	4	Sampling east of plant but west of St. Louis. Second flight aborted due to heavy rain.
	1037	1059	430	---	2	2	

OIL-FIRED POWER PLANT PLUME

Oil-fired power plant plume sampling was performed at both California and Florida locations. Sampling at the Moss Landing plant (located near Monterey, California) was performed during February 1976, while the other plant (located near Clearwater, Florida) was sampled during February 1977. Summaries of these two sampling programs are presented in Tables 4 and 5.

The Moss Landing plant has an installed generating capacity of 2175 megawatts, and is designed to burn gas and/or oil. Serious plume tracking problems were encountered because the plant was operated mostly on gas for the duration of the program. In addition, that portion of the plant operated on oil burned low-sulfur fuel oil (about 0.3 percent sulfur by weight). These two factors resulted in very low plume SO_2 concentrations; at a downwind distance of 1 km, the highest measured SO_2 concentration was 0.4 ppm.

Sampling at the Moss Landing power plant was terminated prematurely because of the low sulfur emissions. The aircraft data were processed and submitted to the EPA Project Officer for review; however, a formal data volume was not prepared because of the inapplicability of the data to analysis of plume sulfur chemistry.

The oil-fired plant in Florida has a generating capacity of 525 megawatts. During the sampling program the sulfur content of the oil was about 2 percent by weight. Ten sampling missions were flown, and included sampling at night and sunrise as well as during the day. Several tests were made using a scrubber on the inlet of the NO/NO_x monitor to evaluate the effects of potential interferences for that instrument.

In addition to the Cessna 206, a single-engine Bellanca Viking, operated by Airborne Research Associates, was equipped to make atmospheric conductivity and potential gradient measurements. This aircraft was used to test the feasibility of using atmospheric electrical measurements for plume tracking and to compare the electrical measurements with aerosol measurements made by the 206 (10). The Bellanca also served as a scout aircraft to locate the plume.

Other participants in the program included Northrop Services, Inc. (program coordination), Environmental Quality Research (meteorological support), Airborne Research Associates (scout aircraft, electric field measurements), and Florida State University (aerosol sampling). The Florida State University research vessel "TURSIOPS" was used as a platform for tethered balloon meteorological measurements. In addition, Brookhaven National Laboratory performed airborne sampling in the same area during the period of study.

TABLE 4. SAMPLING SUMMARY--OIL-FIRED POWER PLANT PLUME (MOSS LANDING POWER PLANT)

Date (1976)	Flight Times (PST) Start	Stop	Tape Cartridge Number	Approx. Plume Sampling Dist. (km)	No. of Sulfate Samples	No. of Impactor Samples	Comments
2/17	1218	1603	501	8	4	0	Plume survey flight east of plant. Plant primarily burning gas --750 MW generated by oil.
2/18	1223	1532	502	8	3	0	Sampling east of plant. Oil-fired generation 750 MW.
2/19	1123	1524	503	8, 18	4	0	Sampling southeast of plant. Oil-fired generation 1450 MW.
	1558	1728	504	34	2	0	
2/20	1110	1156	505	--	0	0	Plume reconnaissance flight. Light wind conditions, plume drifting over ocean. Oil-fired generation 1450 MW.
2/21	1214	1419	---	1, 2, 5, 8	0	0	Plume reconnaissance flight--data recorded on stripchart. only. Oil-fired generation 500 MW.

TABLE 5. SAMPLING SUMMARY--OIL-FIRED POWER PLANT PLUME (LOCATED NEAR CLEARWATER, FLORIDA)

Date (1977)	Flight Times (EST) Start	Stop	Tape Cartridge Number	Approx. Plume Sampling Dist. (km)	No. of Sulfate Samples	No. of Impactor Samples	Comments
2/7	1359	1745	201	---	2	4	Sampling checkout of the plume concentrations and tracking ability. Sampling over the Gulf of Mexico.
2/8	1309	1708	202	3, 40, 80	4	4	Plume characterization. Sampling over the Gulf.
2/9	1640	1900	203	---	0	0	Test of atmospheric electrical measurements for plume tracking. Developed sampling protocol, radio procedures, etc. Sampling over the Gulf.
2/10 & 2/11	2314	0248	204	30, 50	3	3	Nighttime plume sampling. Atmospheric electrical measurements. Special NO_x Experiment. Sampling over the Gulf.
2/11	1602	1930	205	20, 40	3	4	Plume characterization. Special NO_x Experiment. Atmospheric electrical measurements. Plume located over land.
2/12	0658	1054	206	2-3, 45, 90, 135	5	4	Sunrise experiment. Special NO_x Bubbler Experiment. Atmospheric electrical measurements. Sampling over the Gulf.
2/15	1413	1725	208	3, 10	2	4	Cross-comparison flight with Brookhaven National Laboratories. Plume located over land.
2/17	0734	0936	209	1, 3	3	4	Sampling underneath the plume to measure fallout. Eight Nuclepore filters were wing-mounted. Plume located over land.
2/17	1357	1758	210	3, 10	5	4	Plume characterization--coordinated with Florida State University aircraft. Plume located over land.
2/18	0802	1102	211	25, 1-3	3	4	Plume characterization ≈25 km downwind (over land). Sampling underneath the plume for fallout (over the Gulf). Atmospheric electrical measurements. FSU aircraft flying in the area.

REGIONAL SAMPLING

On 10 August 1975, a special flight pattern was used to characterize the distribution of pollutants across a synoptic scale hazy air mass in the Midwest United States. The approximate route of flight was from St. Louis, Missouri, to Kansas City, Missouri, to Indianapolis, Indiana, and return to St. Louis. This mission was conducted as part of the 1975 sampling program in St. Louis, and the other participants were the same as for the urban plume sampling missions (except that correlation spectrometer and winds aloft measurements were not obtained). A summary of this mission is given in Table 6.

TABLE 6. SAMPLING SUMMARY--REGIONAL SAMPLING

Date (1975)	Flight Times (CDT) Start	Stop	Tape Cartridge Number	Approx. Plume Sampling Dist. (km)	No. of Sulfate Samples	No. of Impactor Samples	Comments
8/10	0503	~0840	421	---	13	3	St. Louis-Kansas City-Chillicothe, Missouri
	1012	~1400	419	---	21	1	Chillicothe-Indianapolis, Indiana
	1514	~1800	463	---	5	0	Indianapolis-St. Louis, Missouri

SECTION 4

EXPERIMENTAL METHODOLOGY

Operations of the MRI sampling aircraft were coordinated closely with other participants in the program. The general mode of operations was to use a scout aircraft to locate the plume and set up sampling routes for the MRI Cessna 206. (The use of a scout aircraft was a major refinement of the experimental methodology used in 1974.) The 206 then made a detailed characterization of the plume while the scout moved farther downwind and located the plume again. Both aircraft were in contact with the operations headquarters, which provided guidance for in-flight sampling decisions and coordination with the other program participants. The improvements in air-to-ground communications were another important refinement over 1974.

The experimental methodology related to the operation of the Cessna 206 is described in this chapter. Additional information on experimental methodology can be found in Reference 1. Descriptions of the experimental methods used by other program participants, as well as the manner in which the various sampling platforms were coordinated by the operations headquarters, can be found in the references in the Project MISTT bibliography (Page 43).

AIRCRAFT DESCRIPTION

An instrumented Cessna 206 was used as the primary sampling platform. The 206 instrumentation for this contract was similar, with slight refinements, to that used during the 1974 program (1). A discussion of the Cessna 206 airborne sampling system is presented in Appendix A, along with a list of the changes that were made to the system during this project.

FLIGHT PLANS

The basic flights plans for both urban and power plant plumes consisted of a combination of constant-altitude traverses flown through the plume

perpendicular to its longitudinal axis* and vertical spirals (soundings) flown over a given point. These patterns allowed a detailed characterization of the plume at a particular downwind distance. In addition, horizontal traverses were flown outside the plume to characterize the background environment (Figure 5).

After the plume was located at the desired downwind distance, ground reference points were chosen to allow traverse paths approximately perpendicular to the plume axis. The 206 then made a number of traverses between the endpoints at various altitudes. The number of traverses at each downwind distance depended on the vertical extent of the plume, but was usually at least three, and sometimes ten, or more.

Following the plume traverses, a spiral was usually made as close to the plume centerline as possible. This spiral extended from as near the ground as possible to well above the plume (power plants) or mixing layer (urban plumes). This completed the plume characterization at that distance, and the aircraft then moved downwind and repeated the process. While transiting between downwind distances, the aircraft flew outside the plume and performed background measurements.

CALIBRATION

Several different systems were used for calibration of the continuous gas analyzers on the aircraft. These systems were continually refined during the course of the project. Specifics of the calibration system and procedures used for the February 1977 study are given in Appendix A. The procedures used during the summer 1975 and February 1976 studies were similar, although the systems were different.

Calibrations for the 1975 study were performed by Northrop Services, Inc. A Bendix Dynamic Calibration System was used to dilute a 99.1 ppm NO cylinder and an 11.05 ppm SO_2 cylinder. Gas concentrations in the cylinders were compared to NBS standard reference materials before and once during the field program. Ozone calibration gas concentrations were determined using gas phase titration techniques. The accuracy of the flow regulating capillaries was checked before and after the field program.

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* - It should be noted that it was frequently difficult to ensure that a given traverse was normal to the plume longitudinal axis due to plume wandering, and because the plume was essentially invisible except for near-stack sampling traverses.

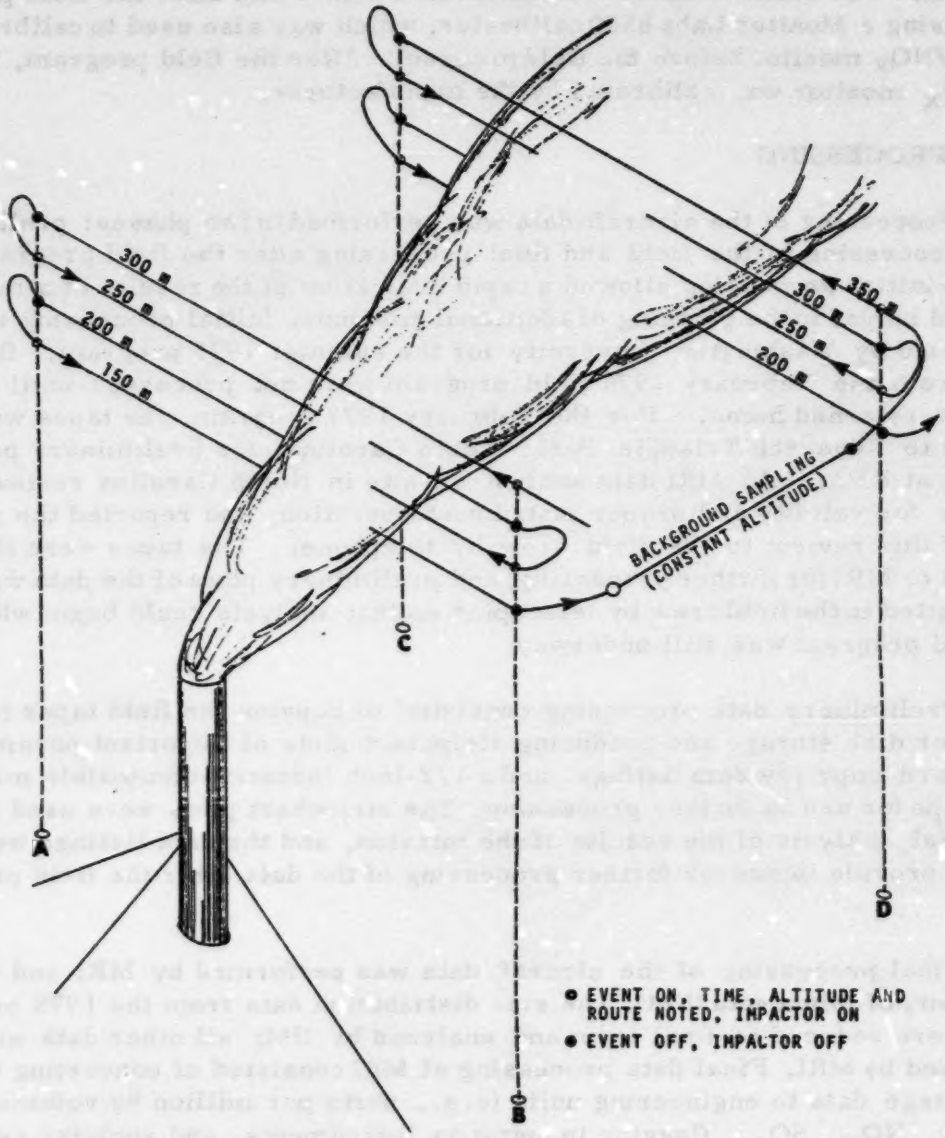

Figure 5. **Traverse flight pattern for plume sampling. Points A, B, C, and D are readily identifiable ground reference points which are determined to allow traverse paths perpendicular to the plume axis.**

For the February 1976 study, a low-concentration span gas bottle (~0.6 ppm) was used to calibrate the SO_2 monitor. The stability of the SO_2 concentration in the bottle was verified by analyses before and after the field program. The ozone monitor was calibrated before and after the field program using a Monitor Labs 8500 calibrator, which was also used to calibrate the NO/NO_x monitor before the field program. After the field program, the NO/NO_x monitor was calibrated by the manufacturer.

DATA PROCESSING

Processing of the aircraft data was performed in two phases: preliminary processing in the field and final processing after the field program. On-site initial processing allowed a rapid evaluation of the results of a mission and helped in the planning of additional missions. Initial processing was performed by Washington University for the summer 1975 program. Data tapes from the February 1976 field program were not processed until the aircraft returned home. For the February 1977 program, the tapes were shipped to Research Triangle Park, North Carolina, for preliminary processing at EPA. An MRI data analyst on-site in North Carolina reviewed the data for validity and proper instrument operation, and reported the results of this review to the field crew by telephone. The tapes were then shipped to MRI for further processing, and preliminary plots of the data were transmitted to the field crew by telecopier so that analysis could begin while the field program was still underway.

Preliminary data processing consisted of copying the field tapes into computer disk storage and producing stripchart plots of important parameters, hard-copy raw data listings, and a 1/2-inch industry-compatible magnetic tape for use in further processing. The stripchart plots were used for the initial analysis of the results of the mission, and the data listings were used to provide inputs for further processing of the data after the field program.

Final processing of the aircraft data was performed by MRI and the University of Minnesota (UM). The size distribution data from the 1975 program were reduced to final form and analyzed by UM; all other data were processed by MRI. Final data processing at MRI consisted of converting the raw voltage data to engineering units (e.g., parts per million by volume of O_3, NO, NO_x, SO_2), flagging inoperative instruments, and applying calibration corrections. A magnetic tape of the final data was prepared, as well as hard-copy plots and/or listings of selected parameters for all sampling runs. These plots were included in the data volumes for the project (11, 12), along with sampling maps and summaries for each flight.

SECTION 5

ELEMENTAL COMPOSITION OF AEROSOL SAMPLES

INTRODUCTION

During July and August 1975, impactor samples of atmospheric aerosols were collected in the St. Louis, Missouri area as part of Project MISTT (Midwest Interstate Sulfur Transformation and Transport). These samples were collected to allow determination of aerosol size and chemical composition characteristics by microscopic analysis. Subsequent to the microscopic analysis, the samples were analyzed for elemental composition using ion-excited x-ray emission (IEXE) techniques. In this chapter, the sample collection and IEXE analysis methods are described, and the results of the IEXE analysis are presented. Results of the microscopic analysis were presented by Draftz et al (13).

Four types of samples were collected: coal-fired power plant plume, St. Louis urban plume, background (outside of plume), and regional (samples collected over a large area between Kansas City, Missouri, and Indianapolis, Indiana). MRI's Cessna 206 was used to collect the samples. A total of fifty-nine (59) impactor sample sets were obtained; each set consisted of two size cuts plus a backup filter. The impactor stages had 50 percent collection efficiencies (D_{50}) of 3 and 0.4 μm diameter.

SUMMARY OF RESULTS, CONCLUSIONS, RECOMMENDATIONS

For the 1975 sampling program, the impactor sample substrates and collection system were optimized for microscopic analysis. Many of the procedures used to optimize for microscopy were in severe conflict with the requirements for elemental analysis. Some of the conflicting procedures were the use of glass-fiber backup filters instead of Nuclepore, the absence of a collection grease on the sample substrates, and the presence of a thin layer of gold on the collection substrates. Elemental data were not obtained from the glass-fiber backup filters because of incompatibility with IEXE analysis. The size selectivity of the impactor was probably poor because of the high possibility of particle bounce from the ungreased collection substrates. Finally, the gold-coated substrates caused interferences that could

not be accounted for; these interferences probably caused masking of some elements and generation of spurious signals corresponding to other elements.

As a result of the system optimization for microscopy, the IEXE data cannot be used to draw definitive conclusions. The data were evaluated on a qualitative basis to gain a better understanding of the elemental composition of the aerosol samples, however, even qualitative results must be tempered by the high degree of uncertainty in the data. The results can be used as an example of the type of information that is available using IEXE analysis, and may provide an indication of the composition of aerosols in the St. Louis area.

In general, the most common elements detected in the aerosol samples were silicon, sulfur, and chlorine. Together, these three elements comprised over two-thirds of the aerosol mass. The abundance of sulfur in the urban and power plant plume samples was expected because these sources are rich in sulfur; the abundance of sulfur in the background and regional samples indicates that sulfur-containing aerosols are widely distributed in the atmosphere and must be considered as a regional-scale pollutant. Furthermore, because the regional samples were collected in a very hazy airmass, the predominance of sulfur in these samples is probably indicative of the role of sulfur compounds in visibility reduction in large-scale hazy airmasses. Silicon and chlorine are largely of natural origin, and their relative abundance in all types of samples is indicative of their widespread occurrence in the atmosphere.

The aircraft sampling methods for power plant plumes caused a large amount of background air to be included in the samples. The data reflect this problem, because the composition of power plant plume samples is similar to that of the background samples. The contribution of the power plant is apparent in the data, however, because of the presence of such typical power plant plume constituents as vanadium, titanium, and potassium.

The urban plume samples were notably lacking in lead, a major component of automobile exhaust. Although interferences from the gold-coated substrates could be the reason, another likely explanation is that lead-containing particles were too small to be collected on the last stage of the impactor. This hypothesis could not be confirmed because the backup filters were not analyzed. Other missing elements in the samples (which would be expected to be present) were calcium (a major component of soil) and iron (power plant plume samples only). No explanation was found for the absence of these elements, and further work would be required to determine if their absence is significant or an artifact of the sampling and analysis method.

The airborne impactor system was proven to be a feasible way to collect atmospheric aerosol samples. If optimized for analysis by IEXE techniques, the system may allow identification of the contribution of various sources to ambient aerosol concentrations (e.g., by using vanadium as a tracer for power plants. For further applications of the system, it is recommended that the following items be performed:

- Calibrate size selectivity of impactor
- Optimize substrates for IEXE analysis (mylar substrates coated with grease, Nuclepore backup filters)
- Use longer sample collection times
- Use plume sampling flight patterns that do not include background air in the sample (e.g., plume orbits)
- Collect a larger number of background samples
- Analyze a larger number of blank (control) samples.

Many of these steps have been implemented on subsequent power plant plume sampling programs, and have yielded a large amount of information on the differences between plume and background aerosol composition and concentrations.

MEASUREMENT TECHNIQUES

Airborne Impactor System

The airborne impactor system consisted of four inertial cascade impactors installed on the Cessna 206 in a wing-mounted pod (Figure 6). Aerosol size distribution measurement systems were also mounted on the aircraft.

The impactor, based on an MRI commercial product, was designed to collect particulate matter in several size ranges below 15 μm in diameter (Figure 7). Modifications to the commercial design were made to optimize the collection of airborne samples. The airborne impactor consisted of two impaction stages and a backup filter. A third stage, intended to collect large debris (>15 μm diameter) which would generally not be of interest, was used for the first two days of sampling. Use of this stage was subsequently discontinued because microscopic analyses indicated that very little material was collected. The stage cutoffs for the flow rates used are summarized in Table 7.

Figure 6. Airborne Impactor System

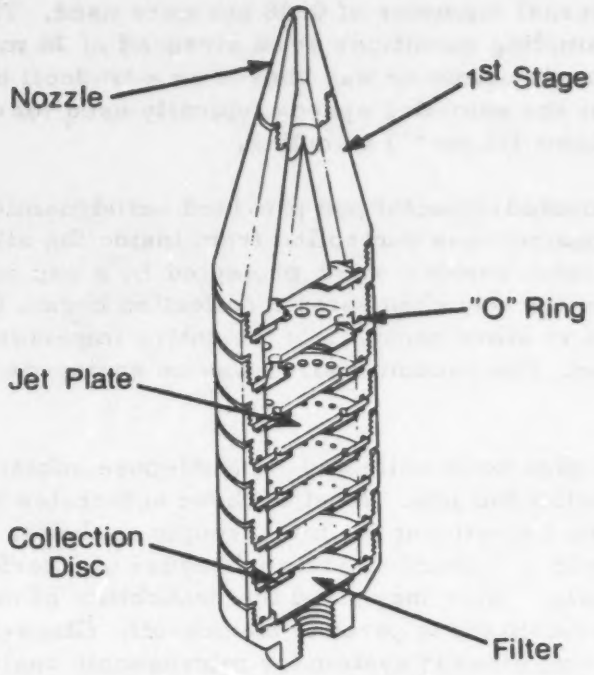

Figure 7. Assembly drawing of MRI Model 1502 Inertial Cascade Impactor.

TABLE 7. DESIGN OF CASCADE IMPACTOR

Stage	Diameter of Holes (cm)	Number of Holes	D_{50} (μm)	Reynolds No. R_N	Mach No. M_N
A*	0.871	8	14.5	1055	0.056
B	0.396	4	3.1	4654	0.054
C	0.053	40 } 10 each quadrant	0.39	3455	0.298

Temperature = 38°C; Flow rate = 56 ℓpm

* - Used for only two days.

One feature of this design which aided analysis of the last stages was the placement of holes in clusters to concentrate the samples (Figure 8). Inlet nozzles with an internal diameter of 0.48 cm were used. These nozzles allowed isokinetic sampling conditions at an airspeed of 36 ms^{-1} for a flowrate of 50 ℓpm. This nozzle diameter was chosen as a tradeoff between the optimum diameters for the sampling speeds typically used for urban (49 ms^{-1}) and power plant plume (31 ms^{-1}) sampling.

The wing-mounted impactor pod provided aerodynamic stability for the system. Each impactor was controlled from inside the aircraft by a solenoid valve. The inlet nozzles were protected by a cap on a movable arm which rotated out of the way when sample collection began. Quick disconnect fittings were used to allow removal of the entire impactor, including inlet nozzle, from the pod. The vacuum source was an engine-driven carbon vane pump.

Aerosol samples were collected on Nuclepore substrates mounted on collection dishes below the jets. Most of these substrates were coated with gold to optimize the experiment for microscopic analysis. The substrates were not coated with a collection grease because of interferences with the microscopic analysis. This increased the probability of errors in the size selectivity of the system due to particle bounce-off. Glass-fiber backup filters were used to optimize the system for microscopic analysis. As will be discussed later, the system optimization for microscopic analysis seriously hampered the trace element analysis.

Impactors were assembled and disassembled in a clean room under a filtered laminar-flow clean hood. Prior to assembly the impactors and nozzles were washed with soap and water and rinsed with acetone followed by distilled water. Careful handling procedures were followed to ensure that the samples were not contaminated.

Aircraft Sampling Procedures

The basic flight pattern used for plume sampling was discussed in Section 4. In general, each plume impactor sample was integrated over several of the traverses made at a particular downwind distance. Impactor sampling was performed during an entire traverse, thereby entraining some background air into the plume samples. Background aerosol samples were obtained during special traverses made outside of the plume.

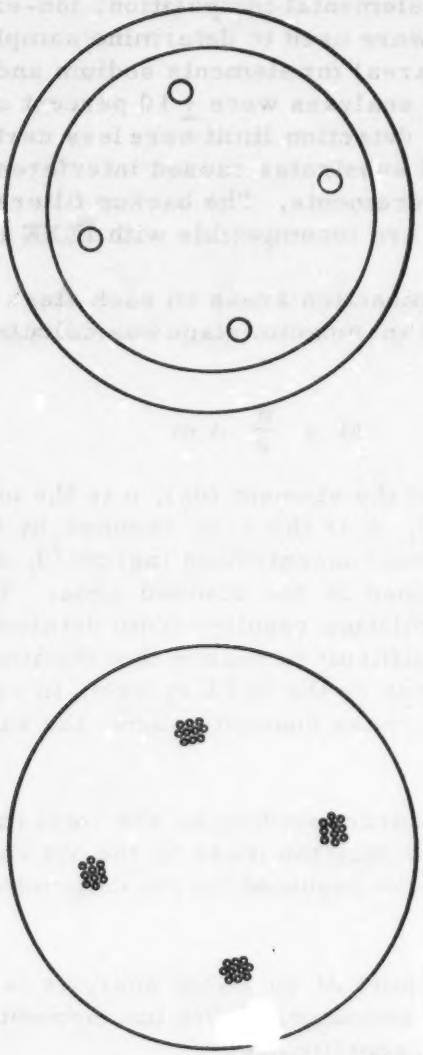

Figure 8. Jet configuration for 3.0 μm D_{50} stage (top) and 0.4 μm D_{50} stage (bottom)

Analysis of Elemental Composition

After microscopic analyses of the impactor samples were completed, they were shipped to Crocker Nuclear Laboratory (University of California, Davis) for determination of elemental composition. Ion-excited X-ray emission (IEXE) methods (14) were used to determine sample mass concentrations (ng/cm^2 of substrate area) for elements sodium and heavier. Nominal uncertainties for the IEXE analyses were $\pm$ 10 percent of the reported value, although values near the detection limit were less certain ($\pm$ 30 percent). In addition, the gold-coated substrates caused interferences which added to the uncertainty of the measurements. The backup filters were not analyzed because glass-fiber filters are incompatible with IEXE analysis.

Only one of the four impaction areas on each stage was analyzed. The total mass of an element on an impactor stage was calculated using the equation

$$M = \frac{n}{a} A m ,$$

where M is the total mass of the element (ng), n is the number of impaction areas on the stage (Table 7), A is the area scanned by the IEXE apparatus ($0.9\ cm^2$), m is the elemental concentration (ng/cm^2), and a is the fraction of the impaction area contained in the scanned area. The greatest uncertainty in the total mass calculation resulted from determination of the value for a, because it was very difficult to ensure that the impaction area was at the center of the area scanned by the IEXE system. In order to allow calculation of approximate total mass concentrations, the value of a was chosen to be 0.5 ± 0.25.

Mass concentrations corresponding to the total mass on an impactor stage were calculated by dividing the mass by the air volume sampled. An uncertainty of $\pm$ 10 percent was assumed for the determination of sample air volume.

An example of the results of an IEXE analysis is presented in Table 8. Several of the problems encountered with the elemental composition data are illustrated in the table, specifically:

1) Signals from the gold-coated substrates tended to "swamp" other elements;

2) Uncertainties increased for elemental masses on the order of the minimum sensitivity;

3) Determination of total mass on an impactor stage contributed as much error as the sample mass measurements.

TABLE 8. EXAMPLE OF ELEMENTAL COMPOSITION DATA[1], IMPACTOR STAGE C (3.0 - 0.4 μm DIAMETER)

Element[2]	Atomic Number	Minimum Sensitivity (ng/cm^2)	Sample Mass[3] (ng/cm^2)	Total Mass On Impactor Stage (ng)	Mass Concentration (ng/m^3)
Na	11	187	206.5 ± 81.0	1490 ± 1330	676 ± 670
Mg	12	117	96.3 ± 26.4[4]	693 ± 540	315 ± 280
Al	13	139	146.1 ± 30.9	1050 ± 750	478 ± 390
Si	14	143			
S	16	170	502.3 ± 67.5	3620 ± 2300	1640 ± 1200
Cl	17	105			
K	19	64	104.3 ± 20.8	751 ± 530	341 ± 280
Ca	20	40	69.2 ± 17.4	498 ± 370	226 ± 190
Ti	22	48	53.4 ± 16.6	384 ± 310	175 ± 160
V	23	40	99.1 ± 20.6		
Cr	24	44			
Mn	25	41			
Fe	26	41	39.9 ± 14.0[4]	287 ± 240	131 ± 120
Co	27	39			
Ni	28	43			
Cu	29	36			
Zn	30	76			
As	33	1599			
Se	34	315			
Br	35	210			
Rb	37	265	335.9 ± 78.3	2420 ± 1770	1100 ± 910
Sr	38	141			
Zr	40	190			
Mo	42	303			
Ba	56	158			
Pt	78	480			
Au	79	953	4021.0 ± 481.8	----	----
Hg	80	712			
Pb	82	167			

(1) Sample integrated over 16 plume traverses 3 km downwind of Labadie Power Plant, 8/7/75

(2) Elements not reported were not detected

(3) Sample mass values and uncertainties as reported by Crocker Nuclear Laboratory.

(4) Sample mass below minimum sensitivity of analysis.

Interferences from gold-coated substrates are thought to be the most significant source of error in the IEXE analysis, particularly because of the possibility that some elements might have been masked completely by the gold. In addition, it is possible that some of the signals identified as being caused by other elements were actually spuriously generated by the gold.

Summary of Measurement Errors

The major sources of error in the elemental composition data are listed in Table 9, along with methods for reducing the errors in the future. The most serious errors were caused by optimization of the system for microscopic analysis, although significant errors were caused by inexperience with the system. It should be noted that the airborne impactor system was developed for the 1975 MISTT program, and experience gained during the program has led to the development of more accurate sampling techniques. Specifically, flight plans involving orbits in the plume for sample collection have provided representative plume samples with sufficient mass for accurate analysis. In addition, techniques have been developed that allow a more precise positioning of samples in the IEXE apparatus. These techniques have reduced the error in the calculation of total mass on an impactor stage from 50 percent or more to about 10 percent.

ANALYSIS

Sampling Summary

Four types of impactor samples were collected: power plant plume, urban plume, background, and regional. Power plant plume samples were collected in the plume of the coal-fired Labadie power plant. This plant, located about 55 km west of the St. Louis Gateway Arch, is rated at 2250 MW gross generating capacity.

Urban plume samples were collected downwind of St. Louis, Missouri. The plume from the industrial/refinery complex at Wood River, Illinois (just across the Mississippi River from St. Louis) was usually imbedded in the St. Louis plume, and was considered to be part of the urban plume.

Background impactor samples were collected in conjunction with urban and power plant plume samples. These samples were collected so that the contribution of the background to plume pollutant concentrations could be determined.

On 10 August 1975, a special flight plan was used to study the horizontal and vertical distribution of pollutants between Kansas City, Missouri, and Indianapolis, Indiana. This regional sampling took place during stagnant, low-visibility meteorological conditions over much of the sampling are-.

TABLE 9. SUMMARY OF SIGNIFICANT MEASUREMENT ERRORS

Source of Error	Approx. Magnitude (Percent)	Method for Improvement
Particle bounce-off or reentrainment	Unknown	Coat substrates with a collection grease
Non-isokinetic sampling	10	Higher-resolution flow measurements
Use of glass-fiber filters, which prevented IEXE analysis	--	Use Nuclepore or paper filters
Spurious signal generation by gold	Unknown	Do not use gold-coated substrates
Masking of real signals by gold	Unknown	Do not use gold-coated substrates
Uncertainties in IEXE analysis system	10-30	Longer sample collection times
Inaccurate positioning of sample in IEXE apparatus	50	More precise positioning of samples in IEXE apparatus
Flow Measurement	10	Higher-resolution flow measurement
Inclusion of background air in plume samples	30	Collect plume samples only while in plume

NOTES: a) Magnitudes of errors generally are rough estimates

b) Errors with unknown magnitudes are believed to be most serious sources of uncertainty

A summary of the impactor samples is given in Table 10.

Elemental Composition of Aerosol Samples

Recognizing that measurement errors make quantitative analyses of the impactor data highly unreliable, the analytical effort was directed towards qualitatively understanding the elemental composition of the aerosol samples. No attempt was made to analyze the change in chemical composition with particle size because of the large potential for particle bounce due to the ungreased substrates. Because the aerosols of primary interest to Project MISTT are those in the accumulation mode (generally 0.1-2 μm diameter), only data from stage C of the impactors (0.4-3 μm diameter) were evaluated.

Before discussing the characteristics of the elemental composition of the aerosol samples, it is important to reiterate the limitations of the data. The size interval covered by stage C is predicted by theory to be 0.4-3.0 μm diameter. The impactor was not calibrated for this program, and the actual interval might be different. In addition, this stage probably collected some particles larger than 3.0 μm as a result of particle bounce from the larger stage. Another major limitation of the data is the interference caused by the gold coating on the substrates. Although the effects of the interference are not known, it is possible that signals from some elements were masked and others enhanced by the gold. No corrections for these effects could be applied to the data.

The average elemental composition of the four types of aerosol samples collected during the program is depicted in Figure 9. Average composition for each category was calculated by summing the mass of each element on all impactors in the category to determine total elemental mass. Elemental masses less than the detection limit of the IEXE system were not included in the sum. Total detected sample mass was calculated by summing the total elemental masses for elements with atomic masses between Na and Fe (inclusively). The average contribution of each element (percent of total detected mass) was found by dividing total elemental mass by total detected sample mass.

This method of presenting the data was chosen because it does not include the errors involved in calculating mass concentrations discussed earlier. The drawback to such a presentation is that differences between the distributions can be masked or enhanced by differences in total mass concentrations. For example, an element uniformly distributed in the atmosphere would comprise different portions of the total sample mass for each category even though its mass concentration was constant. This bias in presentation was unavoidable because of the large errors involved in calculating

TABLE 10. IMPACTOR SAMPLING SUMMARY

Date (1975)	Time (CDT)	Mission Emphasis	Number of Samples			
			Power Plant Plume	Urban Plume	Regional	Background
July 17	0730-1330	Urban		4		--
July 18	0700-1900	Urban		4		--
July 24-25	2115-0430	Labadie	4			1
July 28	1315-1800	Urban		3		1
July 29-30	1330-1130	Urban		8		--
August 6	1700-1930	Labadie	2			1
August 7-8	1730-0115	Labadie	6			1
August 8-9	2215-0145	Labadie	3			1
August 10	0515-1745	Regional			4	--
August 11	0745-2130	Urban		3		3
August 12	0800-1515	Urban		4		--
August 13	0645-1100	Labadie	4			2
		TOTAL	19	26	4	10

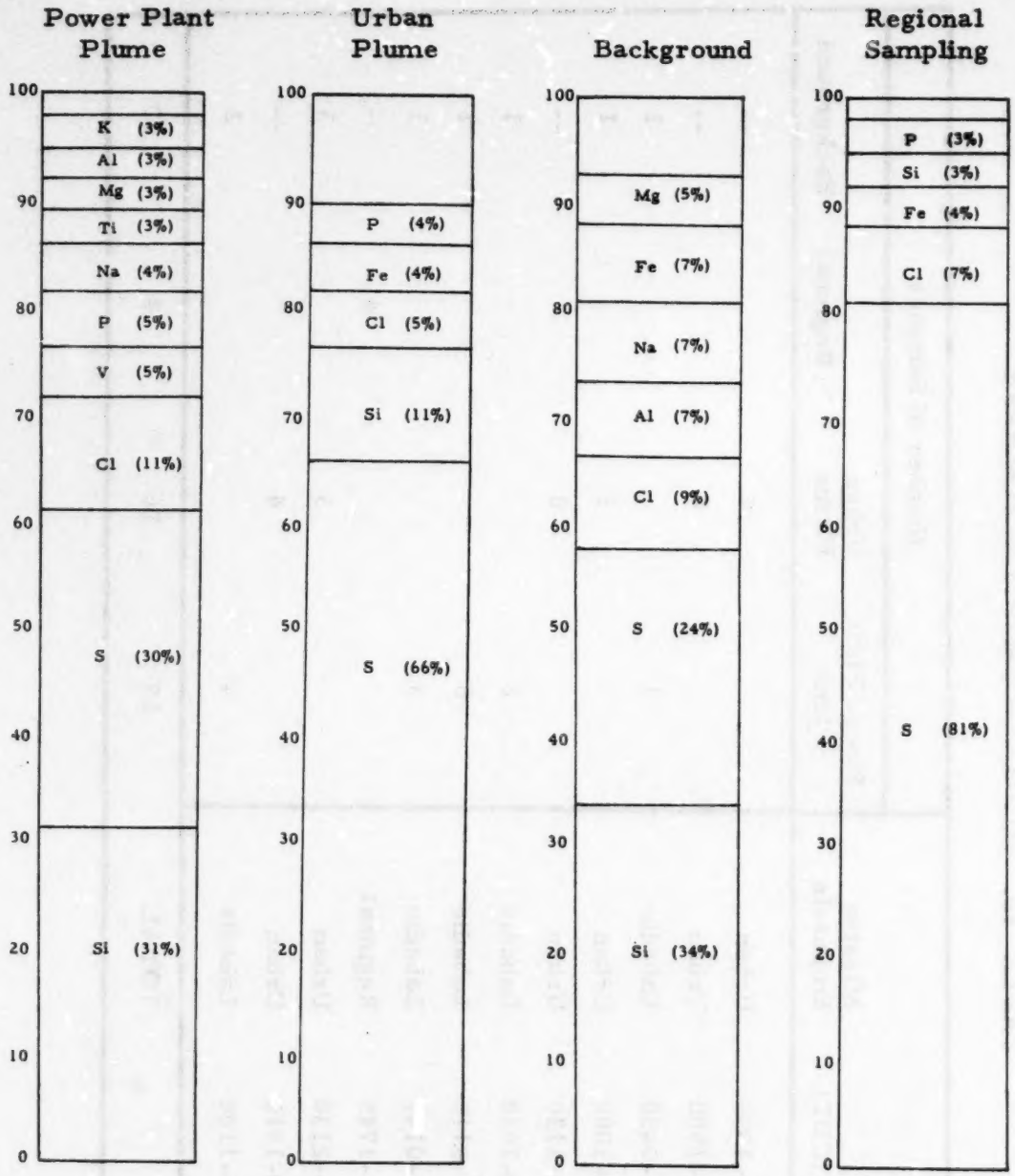

Figure 9. Elemental composition of aerosol samples (0.4-3.0 μm dia). Reported values are averages for all samples collected on gold-coated Nuclepore substrates. Only elements with atomic masses between Na and Fe (inclusively) are included in total. Elements comprising two percent or less of the total mass are not listed.

mass concentrations. For future studies, a more representative presentation would be to scale the height of each column in Figure 9 by the average mass concentration for that category.

One obvious feature of the distributions in Figure 9 is the predominance of sulfur. The fact that sulfur is a major species in all four types of samples indicates that it is widely distributed in the atmosphere, and thus must be considered a regional as well as a local-source pollutant. However, the abundance of sulfur in the regional sampling data is somewhat surprising, because intuitively the expected composition should be similar to that for the background samples. One explanation for the pronounced difference is that the background distribution is an average covering several days with varying meteorology, while the regional samples were collected over a time period of about 12 hours in a very hazy air mass. The regional samples may be indicative of the dominant role played by sulfur in visibility reduction in large-scale hazy air masses. This subject is discussed further by Husar et al (15).

The similarity between the power plant plume and background sample composition is probably a result of the manner in which samples were collected. Because a large amount of background air is sampled during plume traverses, the two types of samples should be similar. The effects of the power plant plume can be observed in the data, because such typical plume constituents as vanadium, titanium, and potassium were observed in significant quantities (> 2 percent of total mass) only in the power plant plume samples.

The other major elements in the aerosol composition, silicon and chlorine, are primarily of natural origin. Although silicon is a common element in power plant plumes, its primary origin is soil. One possible origin of the chlorine is sea salt advected into the area from the Gulf of Mexico.

One element that was not detected in the urban samples (and that might be expected to be present) is lead, a major component of automobile exhaust. However, work by Flocchini et al (14) indicated that most of the lead in urban aerosols is present in the 0.6 μm diameter and smaller size range. This could be the reason for the lack of lead in the St. Louis urban plume samples, although this hypothesis would require analysis of the backup filters for confirmation.

Two aspects of the elemental composition data that were unexpected, and for which no plausible explanations could be found, are the lack of iron in the power plant plume samples and the lack of calcium in all samples. Although these elements were present in small quantities (< 2 percent of

total mass), a substantially greater percentage was expected. Coal-fired power plants are generally considered to be major sources of iron, and their plumes should contain significant amounts of that element. Likewise, calcium is a primary constituent of the earth's crust, and should have appeared in the aerosol samples. Further work is needed to determine if the absence of these elements is significant or an artifact of the sampling and analysis methods.

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Invited Papers (Continued)

§Wilson, W.E. Midwest Interstate Sulfur Transformation and Transport Study (MISTT): Summary.

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§Blumenthal, D. L., J. A. Ogren, and J. A. Anderson. Airborne Sampling System for Project MISTT.

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APPENDIX A

AIRBORNE SAMPLING SYSTEM FOR PROJECT MISTT

The measurement system installed on the Cessna 206 in the summer of 1976 is described in a paper entitled "Airborne Sampling System for Plume Monitoring", prepared for presentation at the International Symposium on Sulfur, September 7-14, 1977, Dubrovnik, Yugoslavia, to appear in Atmospheric Environment, January, 1978. The system on the aircraft in 1975, and in the winters of 1976 and 1977, was identical, with only minor exceptions:

1) The hydrocarbon/halocarbon sample collection system was not installed in 1975;

2) The stripchart recorder was not installed in 1975;

3) The venturi exhaust was used as the vacuum source for the sulfate sampler in 1975;

4) The optical particle counter electronics were mounted on the floor just aft of the electrical aerosol analyzer in 1975;

5) The impactor system and size distribution measurement system were not installed during the February 1976 sampling program at the Moss Landing power plant;

6) An ultraviolet photometer was installed on the aircraft for the February 1977 sampling program.